TM-583
1600.00
June 1975

Fermilab

MEASUREMENTS OF THERMAL CONDUCTIVITY INTEGRALS

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Introduction

We report here preliminary measurements of thermal conductivity integrals for several materials which have been considered for use in the insulating supports of the Energy Doubler superconducting magnets. These materials are two types of fiberglass-epoxy composites (one of them a Fermilab stock item), stacked chips of alumina, stacked foils of stainless steel and pressed superinsulation. The use of stacked materials[1] takes advantage of the usual poor heat conduction through dusted surfaces in mechanical contact. The measurement of this conduction as a function of pressure is the object of a more complete study.

Apparatus

The very small shear strength of these stacks and their very low thermal conductance suggested a novel geometric arrangement for thermal conductivity integral measurements. Two identical samples are used thermally in parallel on a single geometric axis along which the pressure is applied. The samples, of known geometry (cross section area over length) isolate a "hot pill" from "cold tabs" which are in good thermal contact with liquid helium. Figure 1 is a pictorial representation of this setup which is enclosed by a copper can in the vacuum space of a helium dewar. The hot pill is made of copper and contains an electric heater and a resistance thermometer. This is an unusual arrangement for thermal conductivity experiments, allowable here because the contact surfaces between thermometer and sample do not introduce an appreciable error, in fact it can be considered as part of the sample. For the solid samples, however, corrections are needed and discussed below.

Measurements

The heat Q conducted per unit time through a sample of cross section A and length ℓ between temperatures T and T_o is given by:

$$\dot{Q} = -\frac{A}{\ell} \int_{T_o}^{T} k(T')dT'$$

where k(T') is the thermal conductivity of the material at temperature T'. In the case of our stacked material samples, k(T') is an effective thermal conductivity. For our engineering purposes the property of relevance is the effective thermal conductivity integral

$$\int_{4.2}^{T} k(T')dT'$$

The value of this property is directly obtained from our hot pill arrangement by measuring the power $\dot{Q}$ needed to stabilize the hot pill at temperature T and normalizing $\dot{Q}$ by the geometrical factor $2A/\ell$.

The data is plotted in Figure 2. The temperature range covered and the small exposed area of the hot pill kept infrared radiation correction negligible. Another correction too small for relevance in these measurements is the heat leak through the hot pill electrical leads. Four lead dc techniques were used to measure $\dot{Q}$ and the platinum thermometer resistance. This was calibrated against our calibrated Ge thermometer in one of our runs. The error bars are no larger than the symbols representing the data. Some systematic error might, however, be involved in the values of solid samples due to the finite thermal conductance of the contact surfaces with the hot pill and cold tabs. The proper way to eliminate these is to use several pairs of samples, each pair with different ℓ and find the correction by extrapolation to $\ell = 0$. Expediency, however, led us to minimize this error by coating these contact surfaces with high thermal conductivity grease[2] or by inserting a thin indium foil between them and forgoing further measurements. An educated guess is that further correction is not necessary. Cracking of the alumina chips dusted with diamond powder was observed. The thermal conductivity integral of stainless steel[3] is also presented in Figure 2 for comparison.

Conclusions

These measurements provide us with quantitative values for the thermal conductivity integrals of the G-10 material in stock at Fermilab and a similar material used at Brookhaven; they also indicate a very promising material for use in the support system, namely, pressed superinsulation. A cryostat for testing a roller suspension scheme has been built and will also be used for repeating some of these measurements under known pressures. We want to thank G.Biallas for creative discussions.

References

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2. Thermal Compound - a product of Wakefield Engineering Co., Wakefield, Ma.

3. R.B.Stewart and V.J.Johnson, WADD Technical Report 60-56, Part IV, page 13.301 (1961).

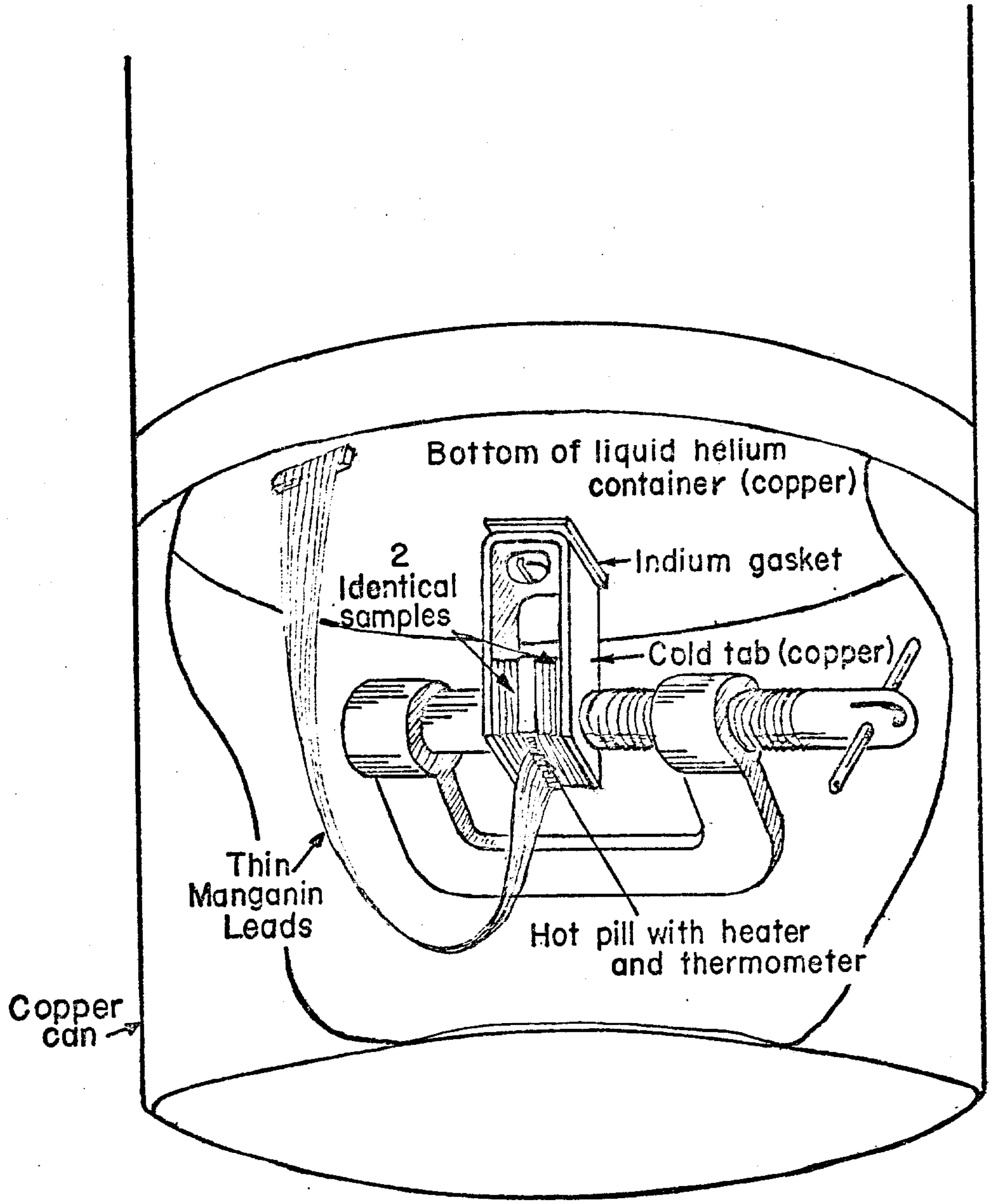

FIG. I

Experimental Setup

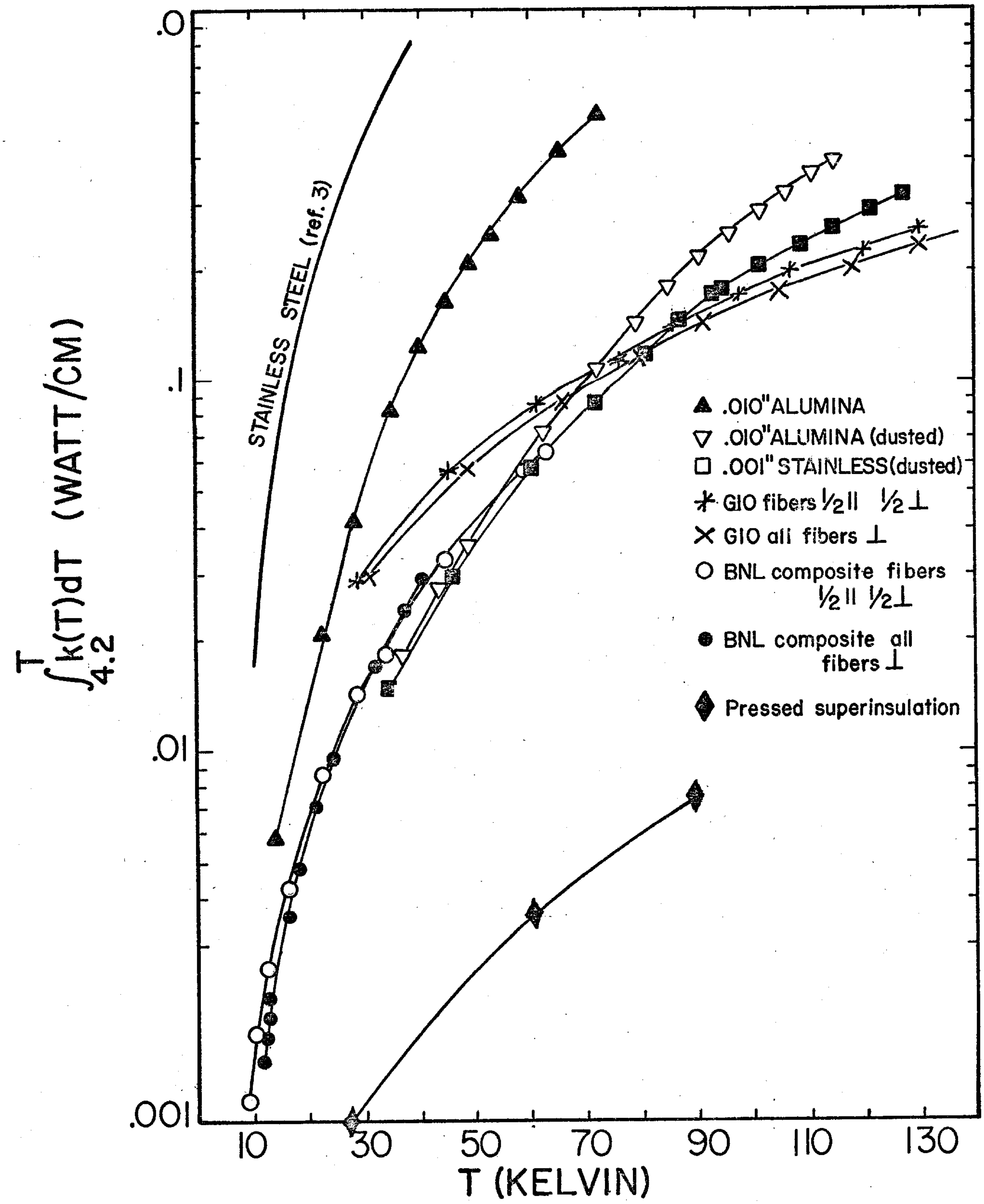

FIG. 2

Thermal conductivity integrals as function of upper temperature for several composite materials.